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INFORMAL REPORT

DETERMINATION OF VOID FRACTION FROM SOURCE RANGE MONITOR AND MASS FLOW RATE DATA

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ABSTRACT

This is a report on the calculation of the TMI-2 primary coolant system local void fraction from source range neutron flux monitor data and from hot leg mass flowrate meter data during the first 100 minutes of the accident. The methods of calculation of void fraction from the two data sources is explained and the results are compared. It is indicated that the void fraction determined using the mass flowrate data contained an error of unknown magnitude due to the assumption of constant homogeneous volumetric flowrate used in the calculation and required further work. Void fraction determined from the source range monitor data is felt to be usable although an uncertainty analysis has not been performed.

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DETERMINATION OF VOID FRACTION FROM SOURCE RANGE MONITOR AND MASS FLOW RATE DATA

INTRODUCTION

During the first 100 minutes of the TMI-2 accident reactor coolant pumps continued to force coolant through the core. At about 75 minutes into the accident the two B-loop pumps were shut off and at just over 100 minutes the A-loop pumps were shut off thus eliminating all forced coolant flow. During this 100 minutes the reactor coolant gradually changed from all subcooled water to saturated water with a high void fraction. Knowledge of the temporal system void fraction during this time is desirable because it will contribute to the determination of the coolant loss rate through the PORV. It will also provide a means for estimating the initial reactor vessel coolant inventory at the beginning of core boildown (i.e., 100 minutes).

Two measurements were made during the first 100 minutes which can be used to calculate the local coolant void fraction: the excore neutron flux measured by the source range monitor (SRM) and the loop mass flow rates measured by the hot leg flowmeters. The object of this study was to establish the validity and accuracy of calculating void fraction based on these two measurements.

The void fraction of the coolant in the primary system, where homogeneous two-phase flow is assumed, varies widely with location. The lowest void fraction should be found in the downcomer and lower plenum and the highest value is in the hot leg. There are major differences between the void fraction as calculated from the SRM (opposite the downcomer and outside the reactor vessel) and the mass flow meter (in the hot leg). At the present time it is not known what the differences in void fractions should be as a function of location in the primary loop but qualitative indications are that the values which have been calculated from the SRM and flowmeter data are at least possible[1,2].

The void fractions calculated from the mass flowmeter measurements had to be corrected for the density used by the computer. There were also errors in the mass flowrate due to variations in the volumetric flowrate caused by the void fraction effect on the coolant pumps. One of the primary assumptions made in calculating void fraction from the mass flowmeter data was that there was a homogeneous constant volumetric flowrate. Making a correction for the volumetric flowrate variation, when it does occur, was beyond the scope of this task and will require a significant separate task.

Time used in this report is in relation to the start of the accident which is defined as the turbine trip time of 04:00:37 on March 28, 1979.

MEASUREMENT CHANNEL DESCRIPTION

This section of the report describes the two measurement channels from which data can be used to calculate primary system void fraction; the source range monitor (SRM) and the hot leg mass flow rate meters. It also describes the hardware, principles of operation, and method of calculating the primary parameters. Background information such as this is useful in understanding how these measurements are used to determine the void fraction and to see the limitations in the methods.

Source Range Neutron Flux Monitor

The excore neutron flux source range monitor (SRM) system was designed to be used during reactor shutdown and at very low reactor power levels during startup. It had an operating range of 0.1 to 10^6 pulses per second, where the normal long term reactor shutdown rate was about 5.0 pulses per second.

The SRM consisted basically of a neutron detector, a signal conditioning and amplifying section, and a strip chart recorder. The neutron detector was a cluster of four BF_3 filled proportional counters connected to operate as a single unit. The detector had an overall length of about 75 cm with a sensitive length of 66 cm, and was mounted at the reactor midplane between the reactor vessel and biological shield. A preamplifier was located in the reactor building to convert electrical charge coming from the detector into a voltage. The voltage amplifiers, discriminator, and power supplies were located in the control building. The output of the electronics was a voltage which was proportional to the logarithm of the incoming pulse rate. This voltage was sent to the stripchart recorder.

The discriminator circuit was used to effectively eliminate the pulses caused by gamma radiation striking the neutron detectors. Engineers determined, after the accident, that the discriminator circuit had been properly set and was still operating effectively. This fact is important, of course, if we are to rely on the detectors to react only to neutron radiation during the accident.

Primary A and B Loop Mass Flow Rate Meters

Each of the primary hot leg coolant pipes had a mass flow rate meter mounted at about the 346 foot elevation in a vertical section of pipe. A resistance temperature detector (RTD) was mounted downstream of each flowmeter at an elevation of about 352 feet. These RTD's were designated RC-4A-TE1 and RC-4B-TE1 for loops A and B, respectively. The designation for the flowmeters was RC-14A-FT and RC-14B-FT for loops A and B, respectively.

The flowmeter consists of a velocity head detector, a signal conditioning and amplifying section, a coolant density computation section, and recording on the reactimeter. The detector was, basically, a pair of pitot tubes, one facing upstream and the other facing downstream with the legs connected to a differential pressure transducer. Actually there were four pairs of pitot tubes in each hot leg loop connected in parallel and spaced 90° apart azimuthally around the pipe.

The differential pressure signal (ΔP) was put through a square root extractor and then multiplied by the square root of the coolant density (ρ) (and an appropriate constant) to produce the mass flow rate measurement.

The coolant temperature measured by the RTD was used to determine the fluid density from a curve which represented the square root of steam table values around the normal reactor operating point (2150 psi and between 520 and 620°F). The loop coolant mass flow rate was continually computed according to the equation $m = k \sqrt{\rho \Delta P}$ where k is a constant.

The flowmeter was designed to operate near the normal reactor full power conditions. During the accident the flowmeter continued to indicate mass flow rate but was using an erroneous coolant density once the system depressurized. This density error amounted to about 2% at 540°F when the system was saturated with zero void fraction. When the void fraction was 0.2 the error in density was about 21% at 540°F.

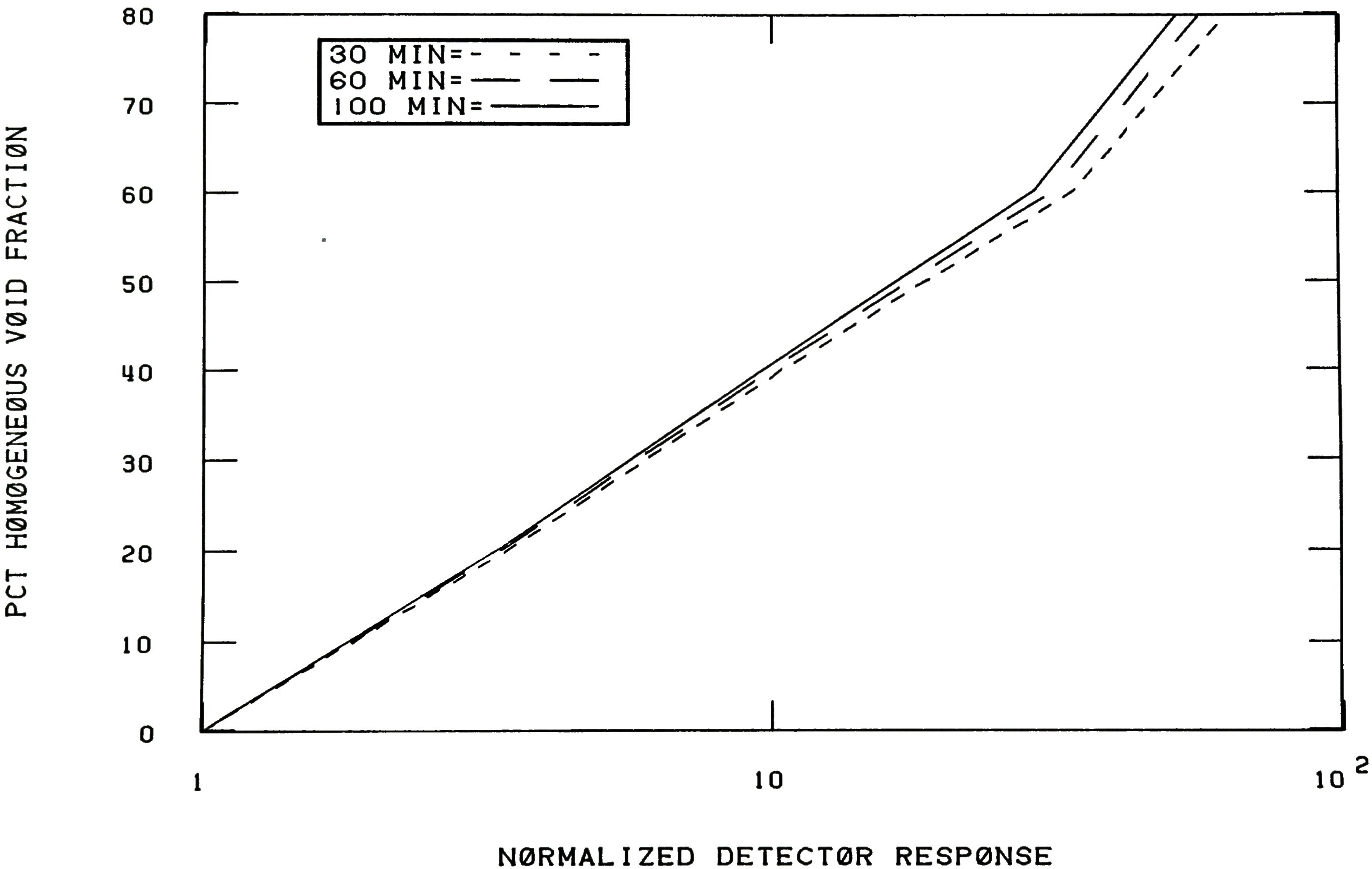
CALCULATION OF VOID FRACTION FROM SRM DATA

Because the SRM detector is located outside the downcomer and the sensitive length of the detector is small relative to the core depth, neutrons produced in the core must travel through the downcomer region before they can be detected. This fact makes the SRM detector sensitive primarily to the shielding effect of the coolant in the downcomer, though there was also a small effect due to neutron production in the downcomer which had to be accounted for in the calculations. The SRM system therefore can be used to determine a coolant density in the downcomer and hence a void fraction if a homogeneous coolant mixture is assumed.

Two separate series of calculations were required to convert SRM count rate to void fraction. First the neutron source had to be determined. Two dominant sources of neutrons were present in the TMI core: neutrons from the two startup sources and photoneutrons from the interaction of fission product decay gammas with the deuterium present in ordinary water. The photoneutron source was calculated using both the ORIGEN and DOT codes[3,4], and the startup sources contribution was neglected because it was about 100 times less than the photoneutron source at 100 minutes. Several one-dimensional neutronics calculations, using ANISN, were then made to determine the core multiplication and the neutron intensity at the detector. Using the results from these calculations along with the effects of coolant density in the downcomer on the SRM response, the degree of voiding assuming a homogeneous mixture in the downcomer was established.

This method of calculating void fraction from the SRM count rate was reported in Reference 3, and the work was repeated by Wu and Baratta[4] as part of the DOE sponsored TMI Accident Evaluation Program. The results from the two separate efforts were in good agreement. Figure 1 is a plot of the normalized detector counts per second versus the percent void fraction from Reference 4, and Figure 2 is the analogue source range monitor data recorded during the first 100 minutes of the accident. The count rate was normalized to the normal reactor shutdown values at 30, 60 and 100 minutes after turbine trip. Figure 3 is a plot of the void fraction versus time from the source range monitor made using the Figure 1 data and the normalized detector count rate from the strip chart recording made during the accident. Data were extrapolated between these three times on Figure 1 using a polynomial curve fit.

There are several sources of uncertainty in the void fraction calculated from the SRM data. First it was necessary to digitize the analogue record of the SRM system response in order to use the computer for calculation and analysis. Second, the interpretation of the response of the neutron detectors to the accident was based on theoretical calculations with ORIGEN and ANISN computer codes using a model of the reactor vessel. An uncertainty analysis will be contained in the final report on the work by Wu and Baratta[4]. Preliminary estimates of uncertainty from this work indicate that calculation of void fraction from SRM data is sufficiently accurate to be usable.



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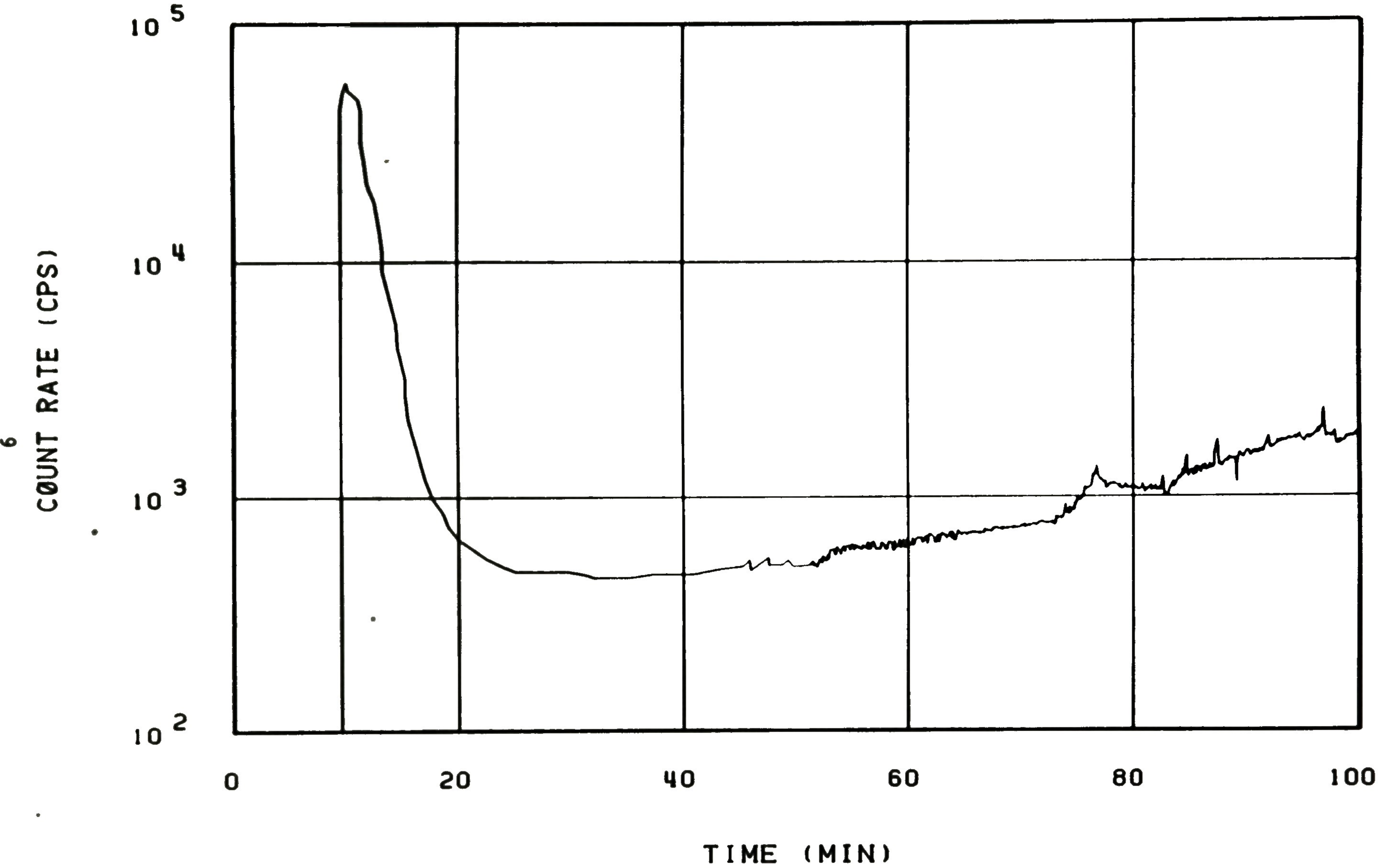


FIGURE 2. SOURCE RANGE MONITOR RESPONSE FOR 100 MIN OF ACCIDENT.

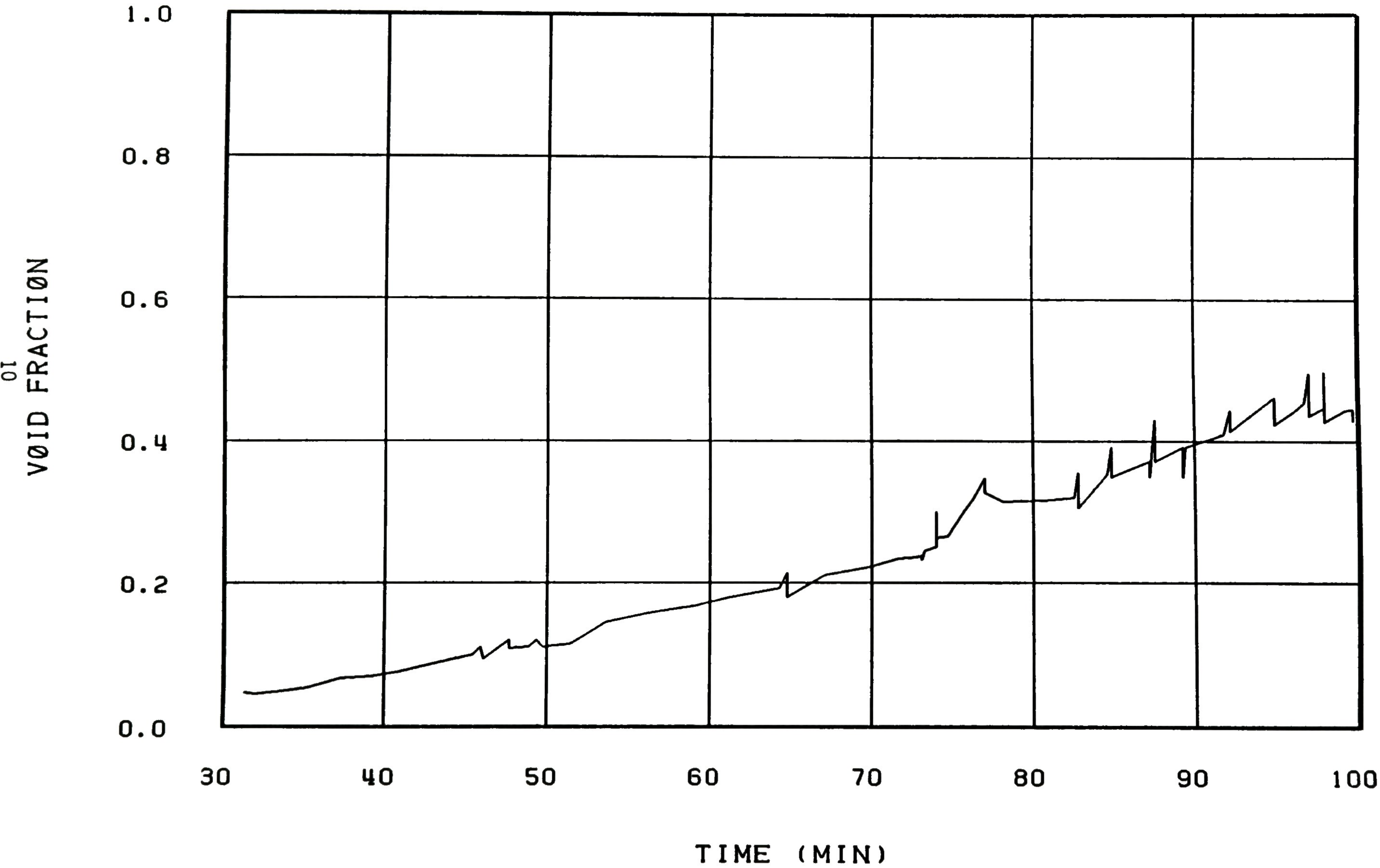


FIGURE 3. VOID FRACTION CALCULATED FROM SOURCE RANGE MONITOR DATA.

CALCULATION OF VOID FRACTION FROM FLOWMETER DATA

The calculation of void fraction of the reactor coolant at the hot leg mass flow rate meter location requires both mass flowrate and coolant temperature data. These data were recorded on the reactimeter at three second intervals giving an accurate record. The mass flowrate ($\dot{m}$) is computed by the electronic system according to the equation

$$\dot{m} = k\sqrt{\rho \Delta p} \qquad (1)$$

where ρ is the density, ΔP is the differential pressure, and k is an appropriate constant[5]. The density value was in error once the loop coolant began to void and the pressure deviated from the normal operation value as discussed in Section II. Using the assumption that the pumps supplied a constant volumetric flowrate and that the flow was homogeneous, one can find an equation for void fraction which compensates for temperature and density corrections needed for the flowmeter[6,7]:

$$\alpha = \frac{1 - \left(\frac{\dot{m}_o}{\dot{m}_i}\right)^2 \frac{\rho_{\ell o}}{\rho_{to}}}{1 - \frac{\rho_{go}}{\rho_{\ell o}}} \qquad (2)$$

where

$\dot{m}_o$ = mass flowrate read from reactimeter,

$\dot{m}_i$ = initial mass flowrate at time 20 min,

$\rho_{\ell o}$ = density of saturated water at temperature of measurement,

ρ_{go} = density of saturated steam at temperature of measurement,

ρ_{to} = density as read by the flowmeter electronics, i.e., from steam table at $\sim$2150 psi and measurement temperature.

(This is based on the assumption that the system coolant had a zero void fraction at 20 minutes.)

Another useful formula for computing void fraction is:

$$\alpha = \frac{\rho_t - \rho_{\ell o}}{\rho_{go} - \rho_{\ell o}}$$ (

where

ρ_t = actual effective density at the flowmeter,

$\rho_{\ell o}$ = density of saturated water at measurement temperature,

ρ_{go} = density of saturated steam at measurement temperature.

Since there were two mass flowrate meters, there are two different curves of void fraction versus time up to about 75 minutes when the loop B pumps were shut off. Figures 4 and 5 show the mass flowrate for flowmeters as it was recorded on the reactimeter for loop A and B, respectively. Figure 6 shows the void fraction as computed using Equation

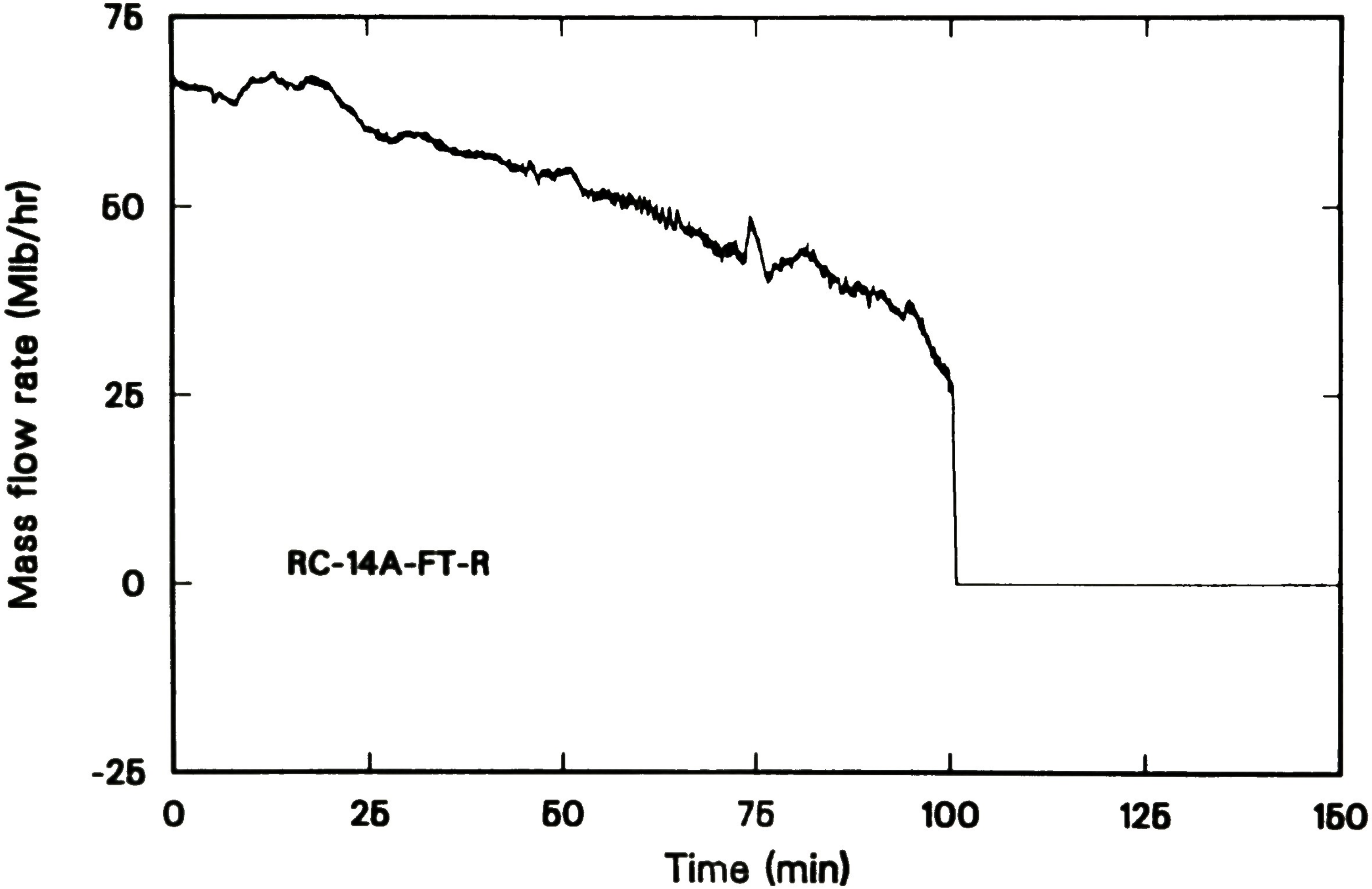
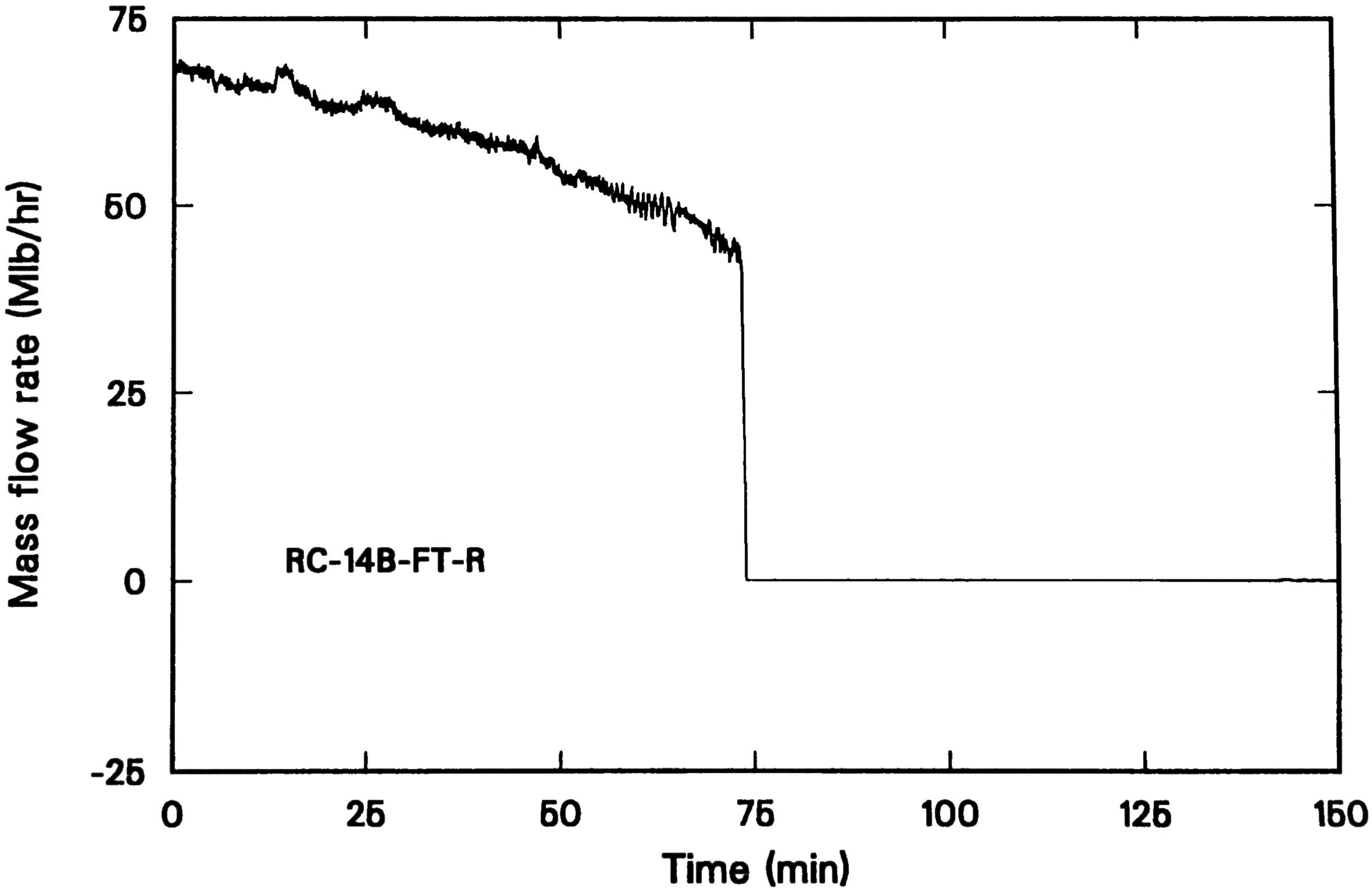


Figure 4. Loop A mass flow rate data during first 100 minutes of accident.


Mass flow rate (Mlb/hr)
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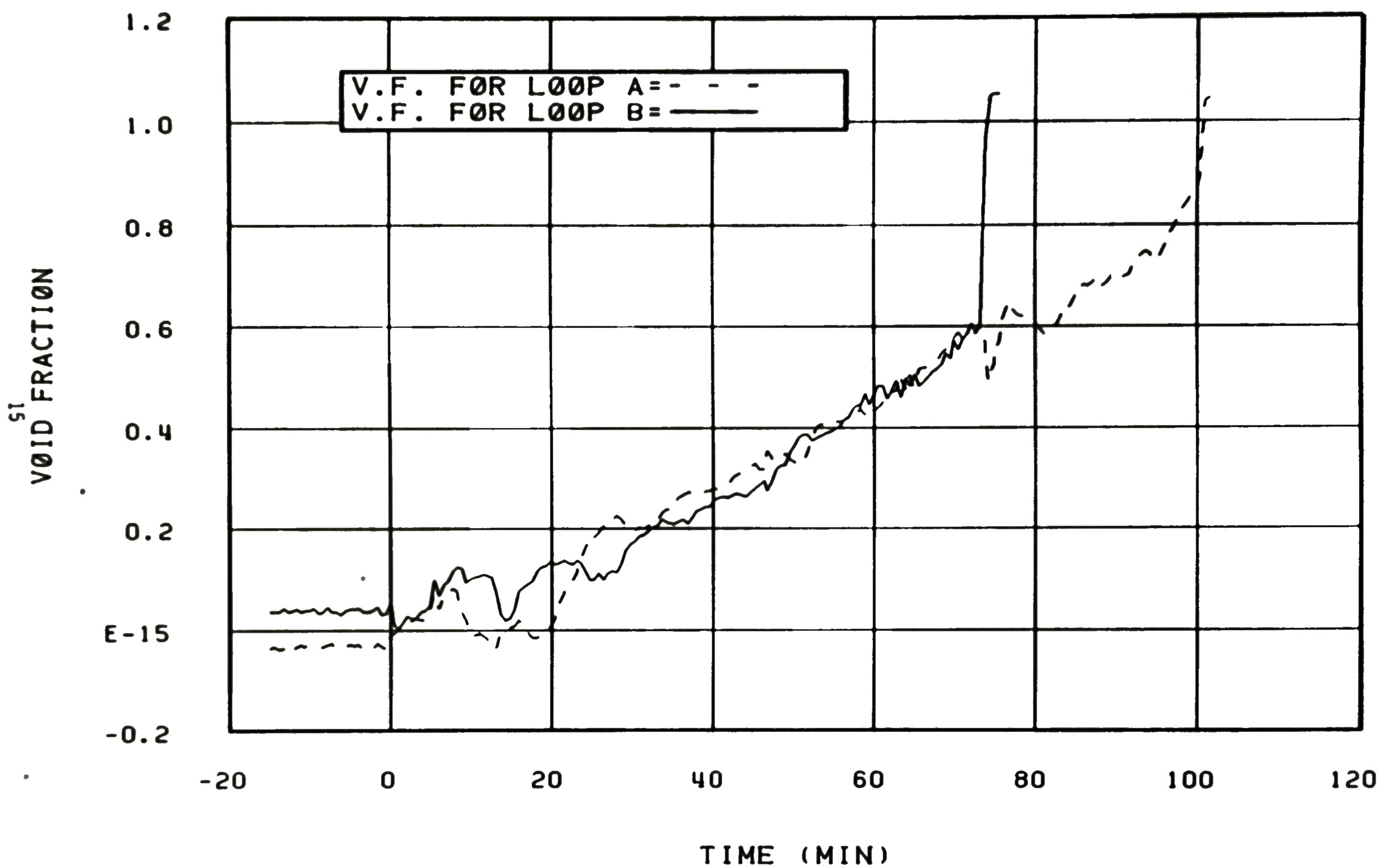


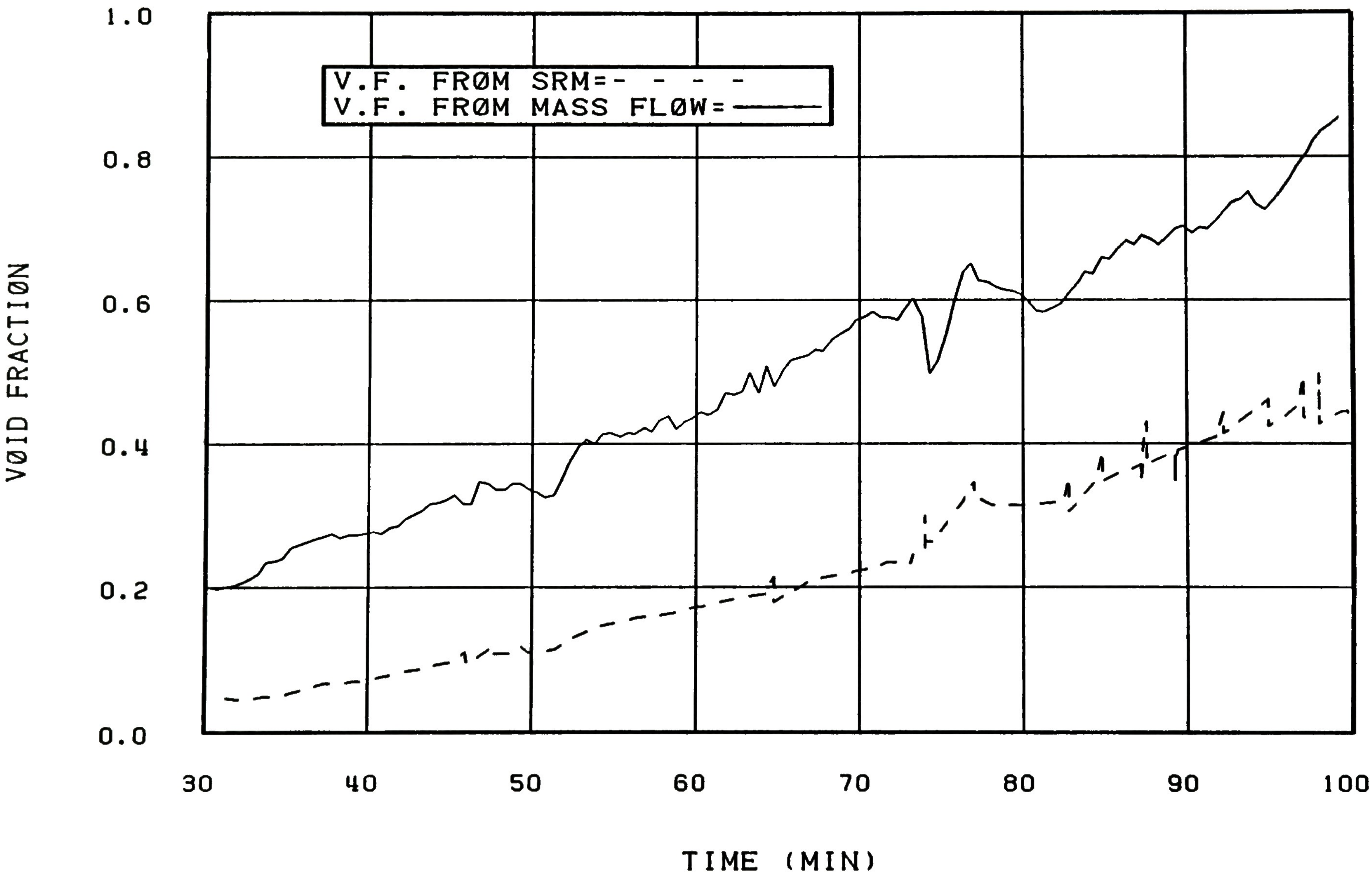
FIGURE 6. HOT LEG VOID FRACTIONS DETERMINED FROM MASS FLOWRATE DATA.

2 for Loops A and B, respectively, using smoothed mass flowrate data. It can be seen that the data are somewhat oscillatory and out of phase, especially at the beginning of the accident. Similar oscillatory void fraction patterns were seen in the calculations presented in Reference 1 for a B&W Bellefonte plant LOCA.

One of the major assumptions made in order to develop Equation 2 for void fraction calculation was that the RC pumps continued to supply coolant with a constant homogeneous volumetric flowrate. This assumption is known to be valid only when the system void fraction is relatively low. Determining the point at which volumetric flowrate drops sufficiently to affect the void fraction calculation is extremely difficult. Qualitative information[1,2] indicates that this could happen at a void fraction as low as 20% at the mass flowrate meter location. References 1 and 2 address several types of primary coolant pumps used in reactor systems including the Bingham-Willamette pump similar to that used on TMI-2. If indeed a correction could be made for the decreasing volumetric flow, the calculated void fraction would be lower than that obtained using Equation 2.

COMPARISON OF VOID FRACTION FROM FLOWMETER AND SRM DATA

Figures 7 and 8 show a comparison of the temporal void fraction as determined from the SRM data and from the mass flowrate meter data. It can be seen that there is a large difference between void fraction as determined from these two sources. Void fraction in the downcomer region as determined from the SRM should be significantly lower than that in the hot leg. The downcomer region coolant is at nearly the lowest temperature and highest pressure of any point in the loop. The hot legs, on the other hand, are at the highest temperature in the loop and at a lower pressure than the downcomer. Logic based on physics, therefore, predicts a lower void fraction in the downcomer region than in the hot leg at the location of the flowmeter. The quantitative difference between the void fraction in the downcomer and the hot leg is not determined at this time.



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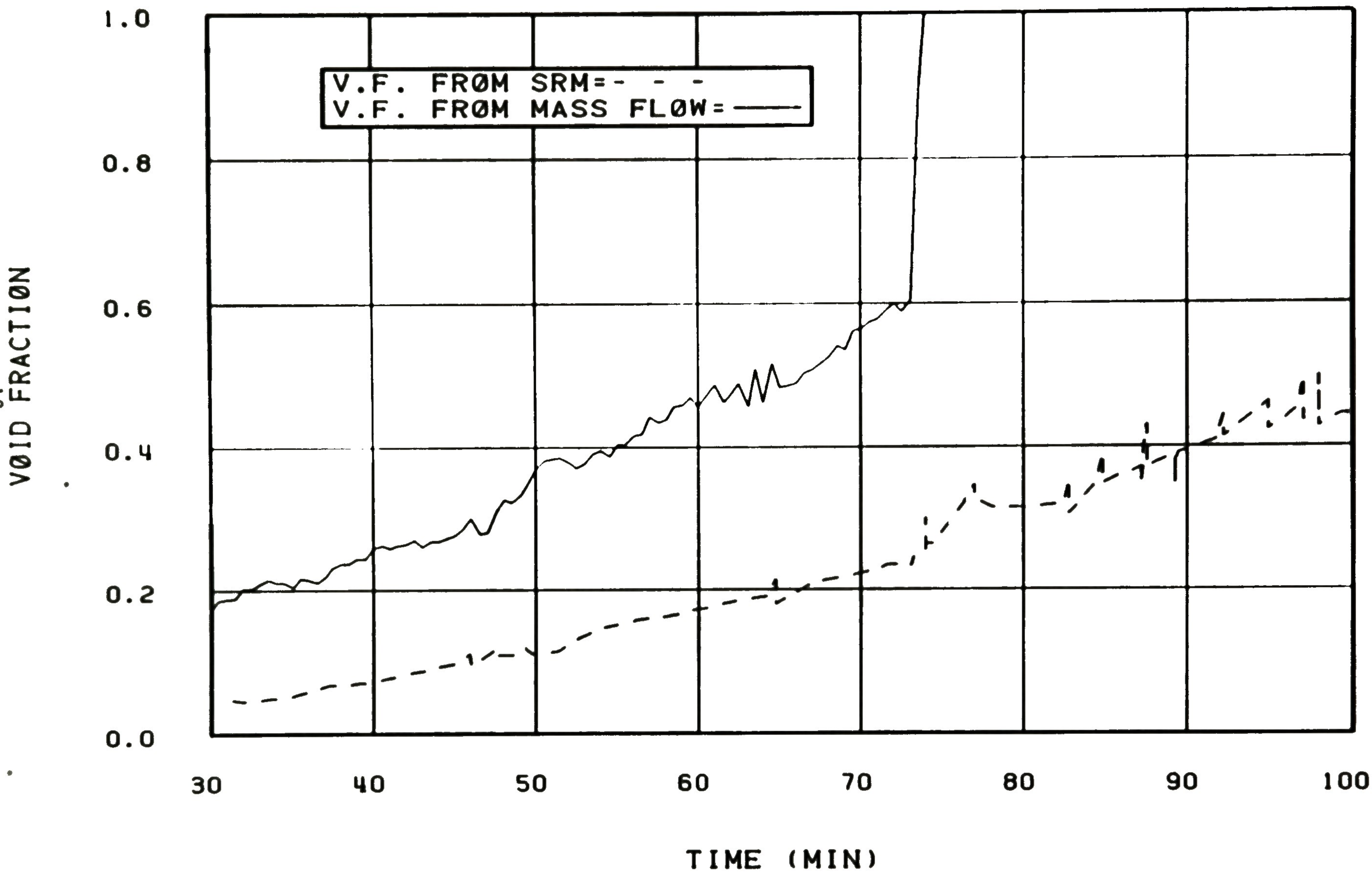

FIGURE 8. COMPARISON OF VOID FRACTION FROM SRM AND HOT LEG B MASS FLOW RATE DATA.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It can be concluded that there are significant differences in the simultaneous void fraction of the coolant between the downcomer region and the flowmeter location in the hot legs. This is caused by the differences in the coolant temperature and pressure between these two locations in the loop. The magnitude of these differences have not been determined theoretically.

The void fractions can be calculated for the downcomer region and the two hot leg regions by using the source range monitor data and the mass flowrate meter data during the first 100 minutes of the accident (while the primary coolant pumps were still operating). Uncertainty is introduced into the SRM data because of (1) the necessity of reading SRM count rate from analog strip charts, (2) the use of theoretical calculations to determine neutron intensities at the detector, photoneutron source, core multiplication, etc. It is believed, however, that the void fraction calculated from the SRM data is accurate enough to be usable.

The uncertainty in the void fraction values calculated from the mass flowrate measurements is presently undetermined because of the inability to quantify the error due to changes in the volumetric flowrate. The conversion of the mass flowrate measurement to void fraction assumed a constant volumetric flowrate. It is concluded that using the flowmeter data to determine the void fraction is not practical because of this undetermined error. It is felt, however, that this method does give an upper bound to the void fraction value in the hot leg. Reasons for this are that corrections for decreasing volumetric coolant flow, which is expected, would reduce the present value of void fraction. Corrections which have already been made for density and temperature on the mass flowrate tended to increase the void fraction value.

Recommendations

It is recommended that a task be undertaken to quantify the error in the mass flowrate meter method of calculating void fraction. This would probably consist of studying pump behavior under two-phase flow conditions to determine how the volumetric flowrate in the primary loop varies with coolant void fraction. This task might include finding how the void fraction varies as a function of location in the primary loop.

References

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6. L. D. Goodrich to R. H. Averill, "TMI System Void Fraction Calculation with Pumps On," EG&G letter BUCK-13-85.

7. S. R. Behling to R. D. McCormick, Private Communication.